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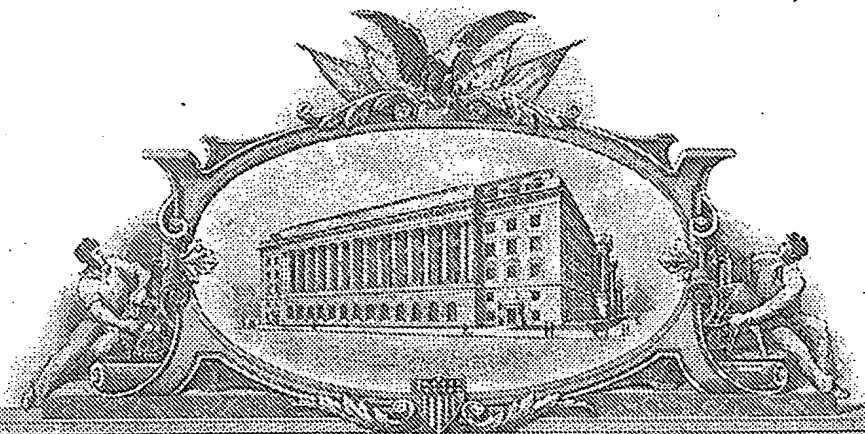
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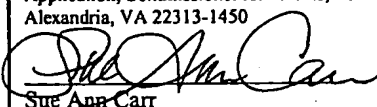
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Components and Resultant Structure there from**

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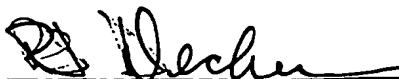
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Dated: December 20, 2004

Respectfully submitted,

By:



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Method and System for Applying Coatings onto the Interior Surfaces of Components and Resultant Structure there from

BACKGROUND OF THE INVENTION

The useful lifetime of small and medium diameter (20 to 40 mm) gun barrels is limited by damage of the interior surfaces resulting from mechanical and thermo-chemical effects related to passing a projectile through the gun bore and subsequent exposure of the interior surface to hot propellant gases. Coatings to protect the interior surfaces of the barrel are therefore frequently employed. Traditionally, the gun barrels have contained chromium coatings that are applied on the interior surface via electroplating. These coatings provide adequate performance; unfortunately hexavalent chrome is created during the electrodeposition process. This material is toxic and difficult to dispose of. Executive Order EO13148 requires the usage reduction of hexavalent chrome (the primary element of electro-deposition) by 50% before the end of 2006. New deposition approaches for wear resistant coatings are therefore desired that retain the high throwing power and affordable cost structure of electroplated chrome but are inherently environmentally safe.

Several other deposition options for protective coatings currently exist. These include approaches such as thermal spraying, chemical vapor deposition (CVD) and the various physical vapor deposition (PVD) approaches. The internal surfaces, however, are hidden from sight making even thickness coating of internal surfaces very difficult or impossible. While high pressure CVD using metal-organic precursors may at first provide a promising approach, non-uniform deposition and vapor toxicity issues plague this approach. Thus, the desired combination of non-line-of-sight coating capability, high deposition uniformity, environmental inertness and compositional flexibility required has been difficult to achieve.

Perhaps the most promising approach is PVD. These approaches are growing in interest for many applications because they are environmentally friendly, allow adequate materials flexibility and enable the deposition of high quality, thin films. In most PVD based processing approaches, however, it is not possible to uniformly coat the interior of hollow tubular substrates without spatially distributed sources (such as cylindrical magnetron sputtering (CMS) where

source targets are inserted into the interior of the part). This arises because the vapor atoms are created in a high vacuum that results in nearly collisionless vapor transport to the substrate. As a result, only regions in the line-of-sight of the vapor source are coated. Even for the cases of thin films deposited with cylindrical magnetron sputtering, deposition rates are relatively low and the vacuum requirements are stringent ($< 10^{-4}$ Pa) so that the cost effectiveness of these approaches in relation to electroplating is in question. In addition, the ability of these processes to deposit coatings into the grooves found in rifled gun barrels is also an issue. Nevertheless, this PVD approach still appears to be one option for coating large diameter gun barrels (> 40 mm). Its application to smaller diameters, however, is not yet clear because of issues related to the stability of the ionization and deposition processes involved.

Thus, the advent of a new deposition process that improves upon the economic and the line-of-sight limitations of current PVD approaches (such as CMS) while retaining their many advantages is of interest for applications such as gun barrel coatings and the coating of other tubular substrates.

Other applications, for example, that would benefit from such advancement include wear and corrosion resistant coatings for the interior surfaces of aircraft landing gear components, wear resistant coatings for actuators in suspension control systems used on automobiles, hydraulic and pneumatic actuators, linear electric motors and the internal surfaces of bearings.

BRIEF SUMMARY OF INVENTION

The present invention provides a methodology and system for applying coatings onto the interior surfaces of components. The approach comprises a vapor creation device (for example an electron beam or laser that evaporates a single or multiplicity of solid or liquid sources), a vacuum chamber having a moderate gas pressure (between 0.1 and 1000 Pa) and a inert gas jet having controlled velocity and flow fields. Vapor created from a source is transported into the interior regions of a component using binary collisions between the vapor and gas jet atoms. Under certain process conditions these collisions enable the vapor atoms to scatter onto the interior surfaces of the component and deposit. By using a vertically translatable deflector plate or secondary gas jets the thickness uniformity and microstructure of the coating can be uniquely

controlled. The result is the ability to deposit monolithic metals or alloys, multilayer coatings, functionally graded coatings and nanoscale composite coatings onto interior surfaces. The present invention method and system approach is environmentally friendly and potentially low cost.

BRIEF SUMMARY OF THE DRAWINGS

Figure 1 – Schematic illustration of a DVD coater used for coating the interior of tubing.

Figure 2 – Aluminum coating deposited onto a stationary steel fiber using DVD.

Significant NLOS coating was achieved on the backside of the fiber (70% of the frontside). The coating morphology was similar on all regions

Figure 3 -- Schematic illustration showing a) process conditions on the interior of the tube that are set to allow lateral diffusion within the jet and deposition onto the interior surfaces and b) the use of a vertically translating deflector plate that alters the streamlines of the carrier gas jet and promotes the deposition of vapor atoms having a near normal angle of incidence in a deposition zone near the vertical position of the deflector plate.

DETAILED DESCRIPTION OF THE INVENTION

In general, physical vapor deposition processes can be considered as multi-step processes; a) vapor creation, b) vapor transport, c) vapor adatom adsorption and d) assembly on the substrate. Methodologies for the creation of the vapor are many and have been widely researched as has the assembly processes at the substrate. There is a need for, among other things, an improved control of the vapor transport processes that enable increased process efficiency, improved composition control and non line-of-sight (NLOS) deposition. Such attributes would promise to greatly improve the economy of PVD processes and its potential range of applications.

One approach of the present invention is to alter the vapor transport step is the use of binary collisions between vapor atoms and a moving background gas. This is enabled by the use of moderate chamber pressures to control the mean free path between vapor / background gas collisions and trans-sonic gas jets to alter the speed of the gas. The result is that several aspects of the vapor transport step can be beneficially controlled. These include the ability to tailor the spread of a thermally evaporated flux to the size of the desired substrate to increase deposition rates, the ability to deposit materials onto non line-of-sight regions of substrates and the ability to control the intermixing between multiple vapor sources.

The present invention Directed vapor deposition (DVD) method and system are an advanced approach based on this innovative concept, **Figure 1**. It provides the technical basis for a flexible, high quality coating process capable of atomistically depositing dense, compositionally controlled coatings onto line-of-sight *and* non line-of-sight (NLOS) regions of components. This DVD technology utilizes a trans-sonic gas jet to direct and transport a thermally evaporated vapor cloud onto a substrate. The vapor is deposited with a high materials utilization efficiency resulting in high deposition rates ($> 10 \mu\text{m min}^{-1}$). Typical operating pressures are approximately in the 1 to 50 Pa range, but may also include the range of about 10^{-4} to about 10^3 torr. Thus, only inexpensive mechanical pumping is required. In this pressure regime, collisions between the vapor atoms and the gas jet create a mechanism for transporting the vapor atoms into regions of components that are not in the line-of-sight of the source and then scattering them onto these surfaces to result in NLOS deposition.

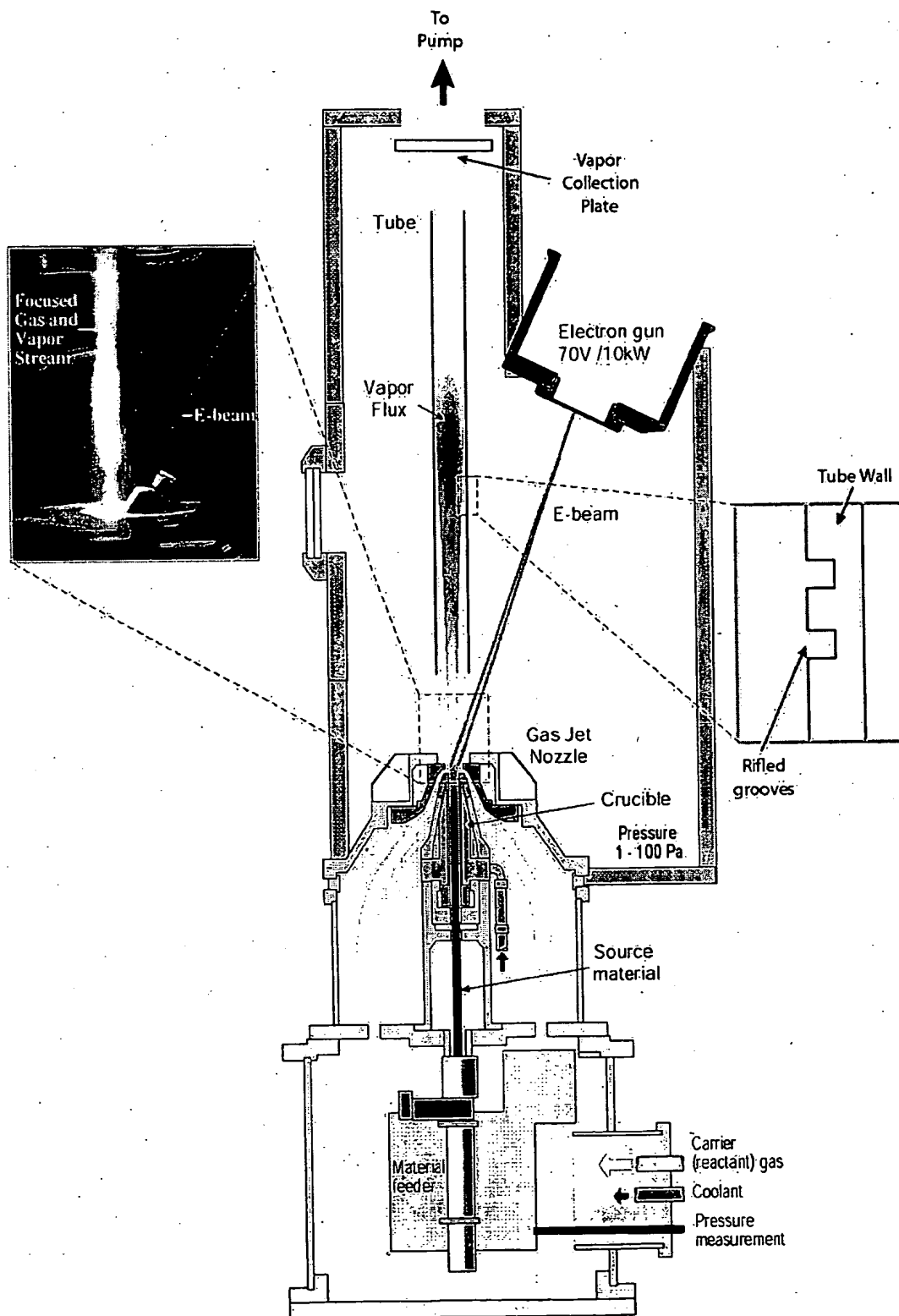


Figure 1 – Schematic illustration of a DVD coater used for coating the interior of small diameter (20 to 40mm) tubing

Additional capabilities include the use of high frequency e-beam scanning (100 kHz) that allows multiple source rods to be simultaneously evaporated. By using the binary collisions between the gas jet atoms and the vapor, the fluxes are intermixed enabling the composition of the vapor flux (and thus, the coating) to be uniquely controlled. Multilayer or functionally graded coatings are created by adding a given e-beam dwell time onto two or more of the source materials.

To enable dense coatings of high melting point materials at low substrate temperatures hollow cathode plasma activation can also successfully be used in this process environment. This enables a large percentage of all gas and vapor species to be ionized. The ions can then be accelerated towards the coating surface by an applied electrical potential increasing the velocity (and thus the kinetic energy) of the ions allowing the coating density to be increased.

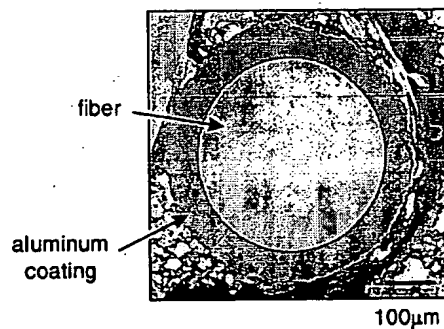


Figure 2 – Aluminum coating deposited onto a stationary steel fiber using DVD. Significant NLOS coating was achieved on the backside of the fiber (70% of the frontside). The coating morphology was similar on all regions

When using the DVD approach as a means for obtaining enhanced NLOS coating (such as the case for gun barrel coatings), chamber pressures are carefully chosen to allow some binary collisions between the vapor and gas jet atoms to enable a mechanism to control the trajectories of the vapor atoms, but not three body collisions that enable the nucleation of clusters that can detrimentally affect the coating microstructure. Significant NLOS coating has been observed

when coating stationary fiber substrates since the gas jet could be used to transport vapor atoms to the backside of the fiber where they could deposit via scattering, **Figure 2**.

An aspect of some embodiments of the present invention system and method allow coating onto the interior surfaces of tubes. Vapor atoms are created using e-gun evaporation and then focused into the tube using a carrier gas where they deposit on the interior via lateral diffusion within the gas flow, **Figure 3(a)**. In this case, the average carrier gas trajectories are parallel to the walls of the tube. However, when the process conditions are set so that vapor atoms have a "random walk" aspect to their motion the vapor atoms only generally follow the carrier gas trajectories and can laterally diffuse via binary collisions.

Control of the vapor atom diffusion process is critical to the successful deposition of high quality, uniform coatings on the interior of these parts and is accomplished by the control of the speed and density of the background gas. When the Knudsen number (i.e. the ratio between the mean free path in a flow to the characteristic length of a body immersed in the flow) for the carrier gas is about equal to or less than 1 and the gas speed is highly subsonic (< 200 m/s) the vapor atoms can diffuse laterally and impact the tube walls with an incidence angle near the substrate normal. Since the carrier gas speed affects the lateral diffusion distances, gradients in the speed from the tube entrance to the tube exit can be used to control the coating thickness uniformity throughout the length of the tube. Another aspect of some embodiments of the present invention demonstrates that the control of the gas speed can also prevent vapor atoms from impacting the surface at oblique angle. Oblique impacts promote shadowing mechanisms that lead to unwanted porosity in the coatings and thus need to be prevented.

Other aspects of some embodiments of the present invention provide for controlling the coating thickness uniformity and angle of incidence distribution at the interior surfaces. For example, when coating the interior of a tube, process conditions that result in a gradual thickness gradient from the entrance of the gas/vapor flux to the exit would benefit from reversing the entrance and exit (by rotating the tube 180°) during the deposition process. Another example is the use of a vertically translatable deflector plate, **Figure 3b**. This could include a cone shaped deflector with small exit points for an argon clearing gas. The deflector would favorably alter the carrier gas trajectories to promote vapor atom deposition in a "deposition zone". By translating the deflector vertically the thickness uniformity could be precisely engineered. The argon

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clearing gas is used to prevent deposition onto the deflector plate and improve the process efficiency. A translatable screen or mask would be used to prevent deposition outside of the "deposition zone". This could be a telescoping design or be made of a flexible material so that the mask would not interfere with the evaporation processes occurring at the source. The uses of pulsed secondary jets moving in the opposition direction of the vapor flux or deflector plates having other geometries are additional options.

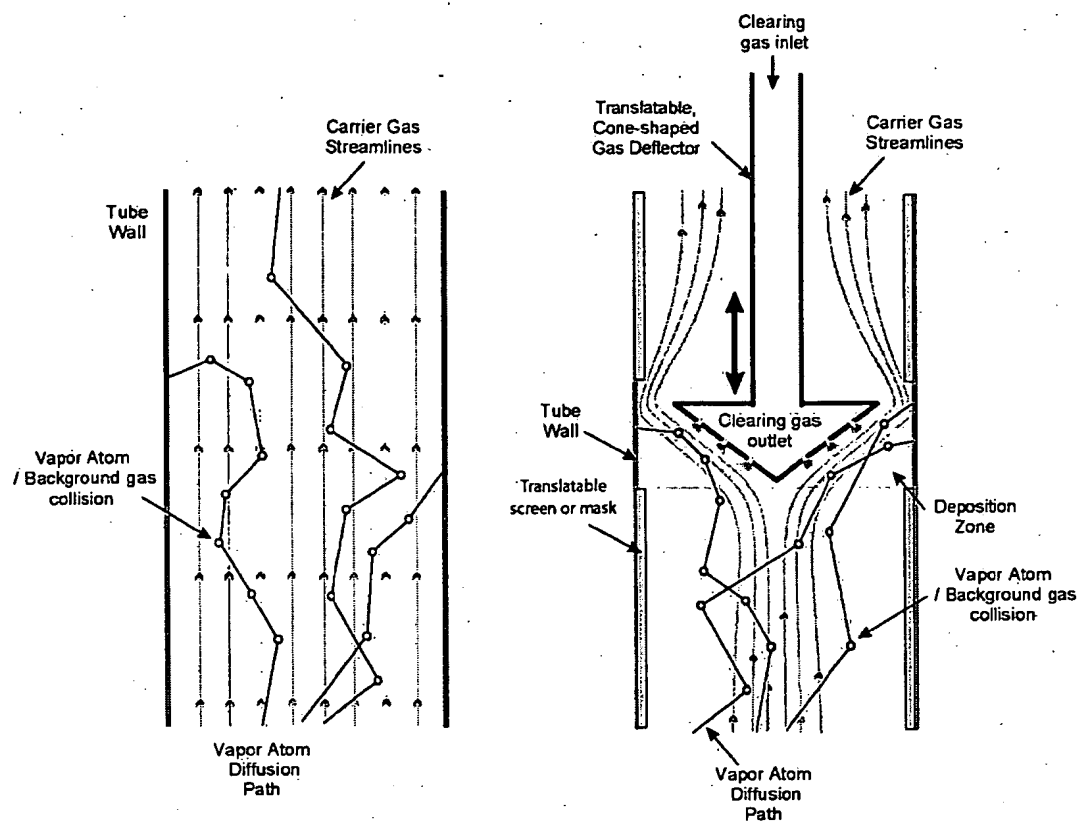


Figure 3 -- Schematic illustration showing a) process conditions on the interior of the tube that are set to allow lateral diffusion within the jet and deposition onto the interior surfaces and b) the use of a vertically translating deflector plate that alters the streamlines of the carrier gas jet and promotes the deposition of vapor atoms having a near normal angle of incidence in a deposition zone near the vertical position of the deflector plate.

The role of the gas jet in enabling NLOS coating and unique deposition characteristics: In most PVD based processing approaches, it is not possible to uniformly coat non-planar substrates without sophisticated substrate translation / rotation approaches or the use of multiple, spatially distributed sources. This arises because the vapor atoms are created in a high vacuum that results in nearly collisionless vapor transport to the substrate. As a result, vapor atoms move in straight paths emanating from the vapor source and only substrate regions in the line-of-sight of the source are coated.

Components requiring coatings on interior surfaces of parts (such as the interior of a tube) present a great challenge for PVD processes since an efficient means for getting vapor into the

interior region is needed as well as the ability to create a uniform, high quality coating on the interior surface. Approaches such as cylindrical magnetron sputtering where sputtering sources are inserted into the interior of the part can be used in some cases, however, even in this case deposition rates are relatively low and the vacuum requirements are stringent so that the cost effectiveness of these approaches in relation to electroplating is in question. In addition, conventional practices the ability of these processes to deposit coatings into the grooves and holes found on interior surfaces is also an issue as is its application to small diameter geometries since the stability of the ionization and deposition processes involved for these parts is not yet clear.

In the DVD approach used here in some embodiments of the present invention method and system, moderate chamber pressures are used (1 to 50 Pa), as well as a range of about 10^{-4} to about 10^3 torr. These pressures are carefully chosen to allow binary collisions between the vapor atoms and gas jet atoms. This enables a mechanism for controlling the trajectories of the vapor atoms. The high purity gas jet prevents the incorporation of impurities from the chamber walls and can in some cases increase the kinetic energy of vapor atoms. In this pressure range, NLOS coating has been observed when coating stationary fiber substrates since the gas jet could be used to transport vapor atoms to the backside of the fiber where they could deposit via scattering.

In another aspect of the present invention, the interior regions of cylindrical tubes can be effectively coated with a dense aluminum layer using the DVD approach (see Figure 1' and 2'). Interestingly, the thickness distribution of the coating could also be controlled by gas jet process conditions. As a result, present invention approach also allows the thickness distribution to be well controlled and tailored to the desired distribution by altering the gas jet properties during the run. Process conditions have also been identified which result in a significant fraction of the vapor atoms impacting the component surface at near normal incidence angles to enable coating microstructures similar to line-of-sight positions to be obtained. This powerful ability of DVD to not only enable vapor atoms to infiltrate into the internal regions of complex components but to control where and how they deposit on the internal regions is anticipated to enable not only the dense, uniform coating of tube interiors, but also more complex coatings approaches to give additional benefits to the use of the DVD deposition environment for landing gear coating.

Some aspects of some of the present invention method and system include, but not limited thereto, the following:

- i) The uniform coating of the interior of tubes having a longer length and a higher aspect ratio than presently used (in an example, from 6" long to 12" long).
- ii) The coating of different coating compositions onto different internal regions of the substrate during a single step deposition process.
- iii) The coating of both the interior and exterior of components with a desired composition using a single deposition step.
- iv) The coating of large components having a "Y" or "T" shape (for example C5 landing gear components) using DVD.

In an approach, to enable the increased length a chamber extension will be placed onto a port in the top of the DVD chamber to yield the additional processing space required to coat the longer, higher aspect ratio tubes, **Figure 12(a)**. To control the thickness uniformity a range of carrier gas flow rates will be employed during the coating run.

For the longer tubes gas flow rates higher than 20 slm (for example) may be beneficial. This is because the higher chamber pressure and gas jet velocity resulting from the increased carrier gas flow will result in a more strongly focused vapor flux. The gas jet velocity decreases as it moves further from the vapor source to increase the probability of NLOS coating deeper into the tube. This is balanced with the reduction in the vapor density as the distance from the vapor source increases (since vapor atoms are continuously depositing onto the tube surface) to determine the coating thickness in regions where primarily NLOS coating occurs. Additionally, increasing the carrier gas flow rate will continue the effect of reducing the relative coating thickness near the tube entrance and increasing the relative coating thickness near the tube exit. By altering the gas flow rate during a given run using conditions with a known thickness distribution, the coating thickness can be engineered by controlling the coating time at each gas flow condition. As a result, a mass flow controller having an increased range will be placed on the coater (a 50 slm maximum range is desired, for example). This will improve the vapor flux focus to increase the coating thickness on the "exit" side of the tube. A smaller gas jet nozzle

opening may also be used. This will increase the pressure ratio of the gas jet which has the effect of increasing the velocity of the gas jet and will also increase the coating thickness of the "exit" side of the tube.

Other additional means may be required to optimize the coating uniformity. If required, other methodologies for controlling the coating thickness uniformity and angle of incidence distribution at the interior surfaces can be provided. For example, process conditions that result in a gradual thickness gradient from the entrance of the gas/vapor flux to the exit would benefit from simply reversing the entrance and exit (by rotating the tube 180°) during the deposition process. Another example is the use of a vertically translatable deflector plate, **Figure 12(b)**. This could include a cone shaped deflector with small exit points for an argon clearing gas. The deflector would favorably alter the carrier gas trajectories to promote vapor atom deposition in a "deposition zone". By translating the deflector vertically the thickness uniformity could be precisely engineered. The argon clearing gas would be used to prevent deposition onto the deflector plate and thus improve the process efficiency. A translatable screen or mask would be used to prevent deposition outside of the "deposition zone". This could be a telescoping design or be made of a flexible material so that the mask would not interfere with the evaporation processes occurring at the source. The use of pulsed secondary jets moving in the opposite direction of the vapor flux are an additional option as are the use of baffles near the tube walls which reduce the gas jet velocity.

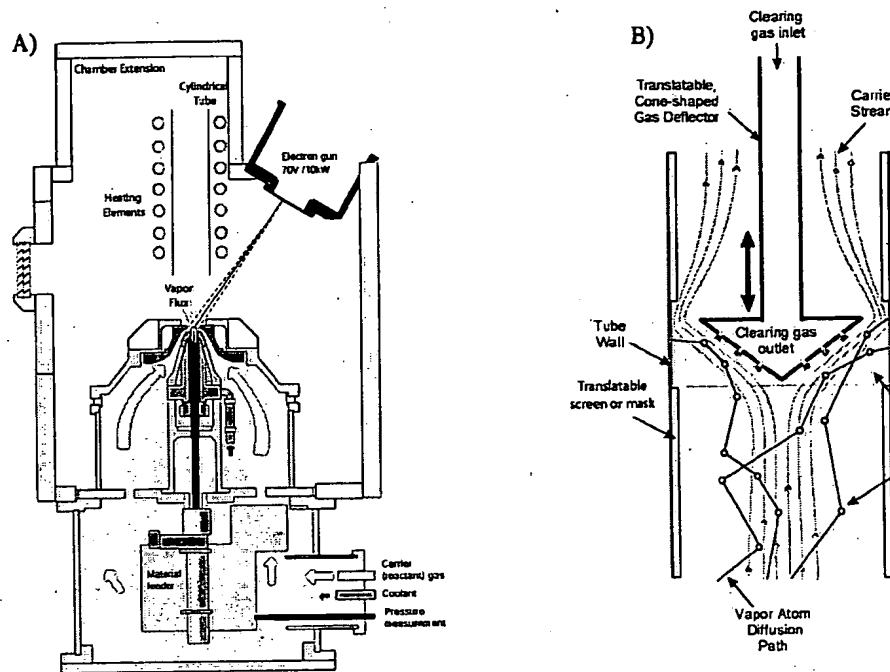


Figure 12 – A) Schematic illustration showing the experimental set-up to be used to enable longer tubes (up to 12" long) to be coated using DVD. **B)** the use of a vertically translating deflector plate that alters the streamlines of the carrier gas jet and promotes the deposition of vapor atoms having a near normal angle of incidence in a deposition zone near the vertical position of the deflector plate.

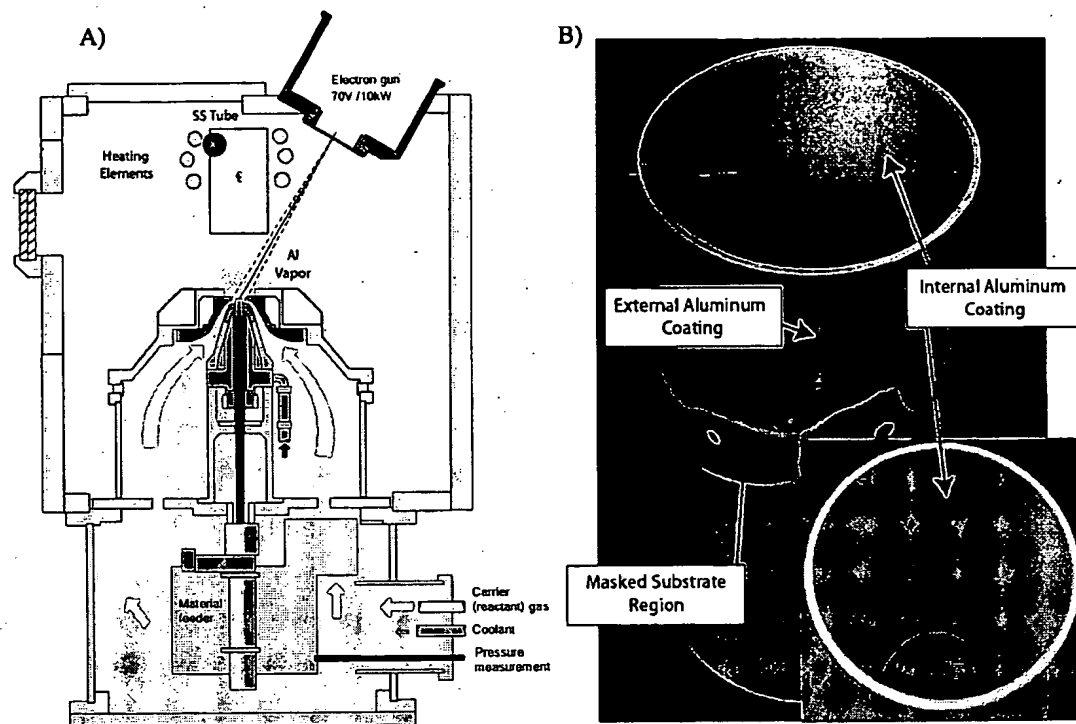


Figure 1' – a) Schematic illustration of the DVD process that will be used for depositing wear resistant coatings. **b)** A 3" diameter, 6" long stainless steel tube coated with aluminum using DVD. Both the interior and exterior surfaces were coated (in a single step) with the exception of exterior surface shielded by the mechanism used to hold the tube in the chamber.

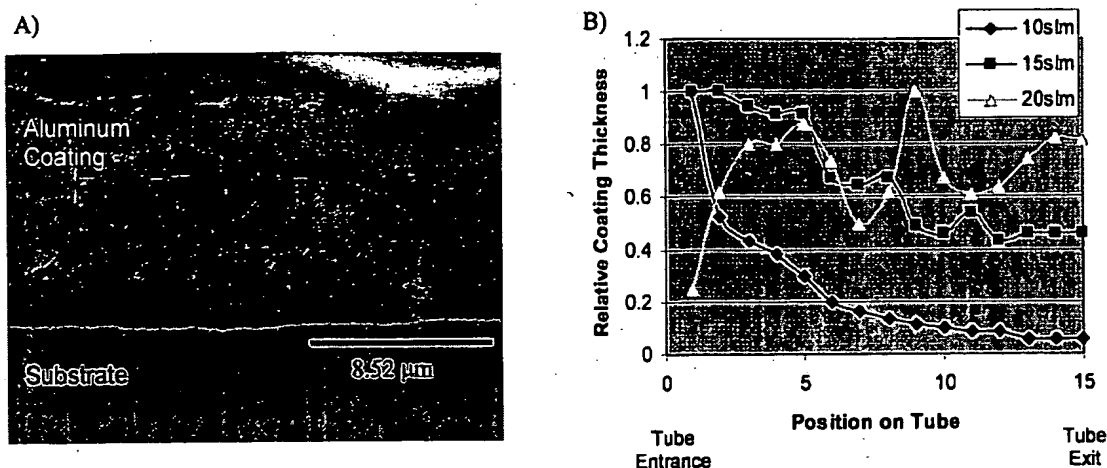


Figure 2' – A) SEM micrograph showing the microstructure of the aluminum coating located at the position marked x in **Figure 1**. **B)** Coating thickness distribution for aluminum deposition along a 3" diameter, 6" long tube using different carrier gas flow rates. Note that as the carrier gas flowrate was increased less coating occurred near the tube entrance and more coating occurred towards the tube exit.

The coating of different coating compositions onto different regions of the substrate during a single step deposition process: for example, large landing gear components require the coatings to have different attributes at different internal locations. For example, some locations experience significant wear and thus, require hard, well adhered coatings to limit damage. Such coatings should also have adequate corrosion resistance. In other locations only corrosion protection is required. While having one coating composition optimized for the elimination of all modes of damage is most desirable it is more likely that the coating composition having the best wear performance will be different than the coating composition giving the best corrosion protection. This situation can be difficult from a processing standpoint since most processing techniques would require multiple processes / processing steps (deposition / masking / grinding) to obtain the desired coating at the desired locations. This at best adds cost to the deposition of the coatings and in some cases limits the ability to deposit the desired coating composition.

The multi-source evaporation capabilities of the of the present invention DVD process and system results in the ability to quickly alter the vapor composition during deposition. This

coupled with the ability to control where the vapor deposits on the substrate by controlling the trajectories of the vapor atoms as well as the use of masking approaches makes the deposition of different coating compositions onto different regions of the substrate possible in a single deposition step.

To demonstrate this concept, refer to the schematic drawing of **Figure 13**. For the case shown, a coating of material **A** is to be deposited on the middle section of the tube interior and a coating of material **B** is to be deposited on the sections near the tube entrance and exit. The initial set-up is shown in **step 1** where a mask is used to shield the outer sections from coating while leaving the middle section exposed. The electron beam is scanned across source **A** to create a vapor flux and a moderate carrier gas flow rate is used. The gas flow rate is chosen to allow most of the atom impacts to occur in the unmasked region. Coating of the mask will occur to some extent, but this is wasted material and should be limited. After the desired coating thickness is achieved in the middle region, the mask is translated upward to mask the middle region and expose the outer regions. The electron beam is adjusted to allow evaporation of only source **B** and coatings with this material begins. The gas jet will initially be set at a high value to facilitate coating growth near the tube exit and then be altered to a low level to facilitate coating near the tube entrance (**step 3**). The final result is a coating having composition **A** in the middle and composition **B** on the outer regions.

In an exemplary embodiment, for example, the process described above on a 3" diameter, 6" long tube (but not limited thereto) is implemented. The DVD system is equipped with high frequency e-beam scanning (100 kHz) that allows the beam to be easily switched from one source to another during a deposition run. In an embodiment, a multi-source crucible (enabling up to four source evaporation) can be used to evaporate aluminum and deposit it on the middle section of the tube interior and then to evaporate copper onto the outer sections. These materials can simply be chosen for their decorative features and this will be followed by the deposition of a wear coating onto the outer regions and a corrosion resistant coating on the middle section once successfully developed.

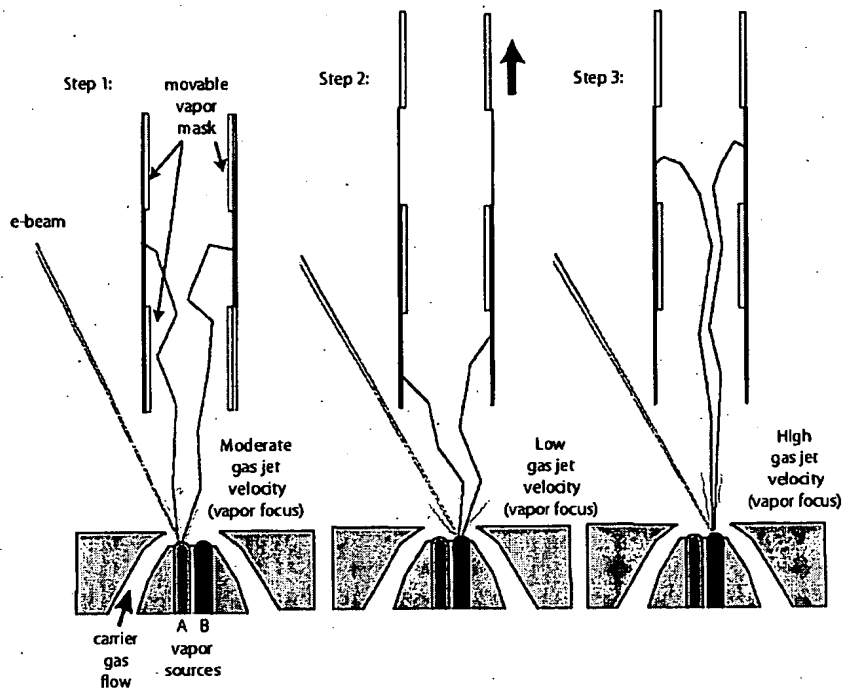


Figure 13 – Schematic illustration of a process to deposit different coating compositions onto different internal regions of a substrate in a single deposition run.

The coating of both the interior and exterior of components with a desired composition using a single deposition step: for example, while some aspects provide for depositing effective coatings onto the interior surfaces of components, in many cases the components will also require wear or corrosion resistant coatings on the exterior as well. Processes do currently exist to apply coatings onto the external regions (i.e. HVOF (wear), IVD (corrosion)); however, the use of two separate processes is not only costly but also inefficient. Thus, processing approaches, as provided by the present invention method and system, allow the simultaneous deposition of the desired coating onto both the interior and exterior regions are highly desirable.

The present invention provides several approaches for achieving the flexibility to control the vapor transport during deposition in the DVD process. Two of these, for example, are shown schematically in **Figure 14**. In the first approach a tube is placed with one tube wall directly above the source while the tube is rotated, **Figure 14(a)**, to obtain circumferential uniformity. This approach is appealing as it would deposit a similar coating thickness distribution on both the

interior and exterior of the tube in a single step. With regards to coating vertically aligned plates it is submitted that while a thicker coating is obtained on the part of the component located nearest the vapor source the thickness only decreases gradually and when coating parts (such as a tube) where the entrance and exit can be reversed (by rotating the tube 180°) during the deposition process, a very uniform coating thickness can be simultaneously obtained on the tube exterior and interior, **Figure 15**. For greater control, a dual-source configuration can be used, **Figure 14(b)**. In this case, the extremely high scanning rate (100 kHz) of the DVD e-beam gun can be used to co-evaporate the desired composition from both sources. A vertical gas jet is used to focus the vapor from the first source into the interior of the component while a horizontal gas jet is used to deposit material from the second source. The coating thickness uniformity is controlled on the interior of the tube by altering the vertical gas jet conditions and on the exterior by translating the horizontal gas jet up and down. The end result is again a uniformly coated part on the exterior and interior. The various methods and systems of some of the embodiments of the present invention would enable different coating compositions to be simultaneously deposited on the component exterior and interior.

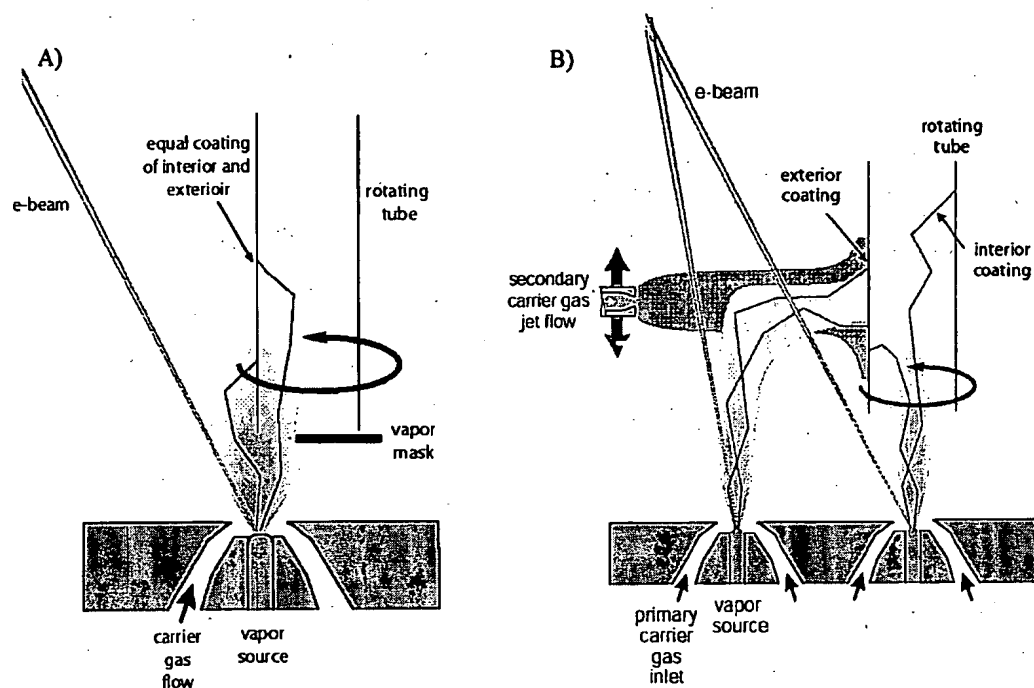


Figure 14 – Schematic illustration showing the simultaneous deposition of a coating material onto the interior and exterior of a tube using a) a single source configuration and b) a dual-source configuration.

In another aspect of the present invention, the simultaneous deposition of a uniform coating thickness onto a tubular component is achieved (for example, 3" diameter, 6 to 12" in length, but not limited thereto) using one of the above techniques.

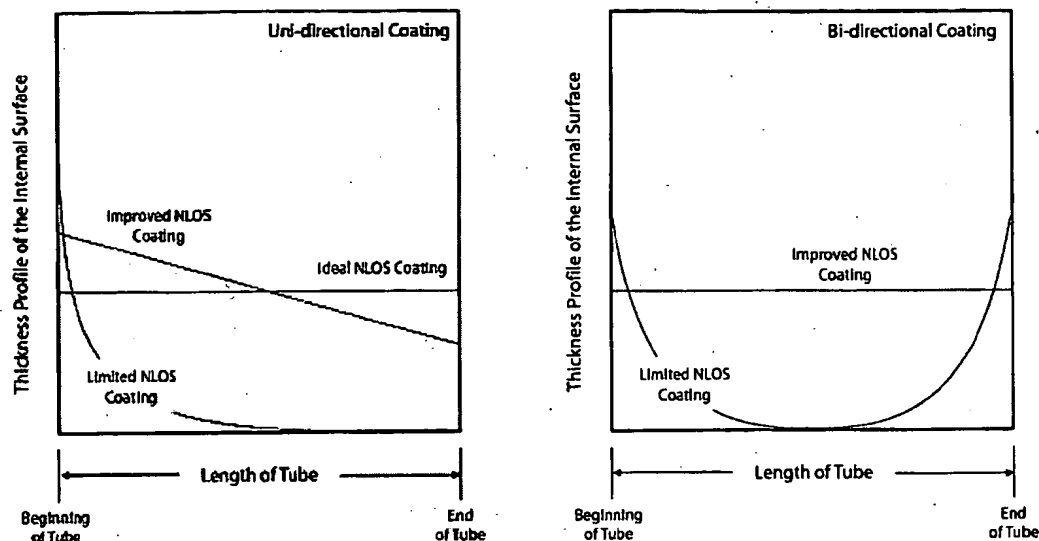


Figure 15 Schematic graphs showing that coating with non uniform thickness down the length of the tube can be improved through the use of bi-directional coating. Process conditions that result in a gradual thickness gradient from the entrance of the gas/vapor flux to the exit would benefit from simply reversing the entrance and exit (by rotating the tube 180°) during the deposition process.

The coating of large components having a “Y” or “T” shape (for example C5 landing gear components) using DVD: An aspect of some of the present invention method and system provides for depositing coatings onto the internal regions of C5 landing gear parts, for example, but not limited thereto. An aspect of some of the embodiments comprises using an advanced electron beam to evaporate material from a centrally located crucible and to use multiple gas jet nozzles having adjustable positions to direct vapor atoms onto all interior regions of this component. A schematic illustration of the coating approach is given in **Figure 3’**.

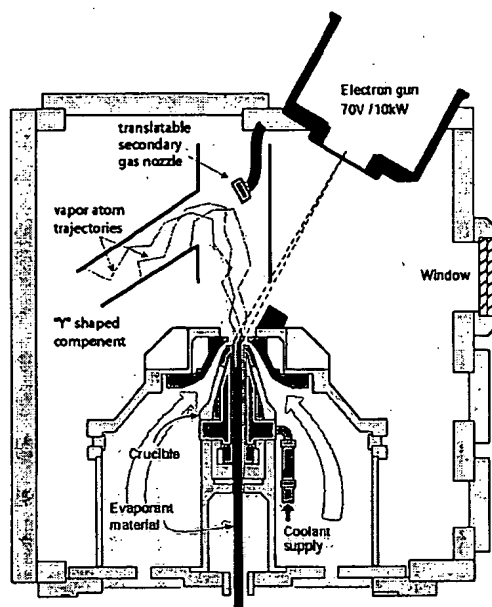


Figure 16 – Schematic illustration of an experimental set-up used to coat a material into the internal regions of a “Y” shaped component.

With regards to another aspect of the present invention embodiments, the deposition of coatings into more complex shapes using similar concepts (on a smaller scale) will also be demonstrated using the DVD coating equipment. The proposed deposition set-up for this work is given in **Figure 16**. The internal regions of a “Y”, “T” or “L” shaped component will be coated using the combination of primary and secondary gas jets.

Some aspects of some of the embodiments of the present invention method and system include, but not limited thereto, the following: the ability to control the thickness distribution on the interior regions of long tubular components, to simultaneously deposit coatings on the exterior and interior of components, to deposit different coating compositions onto different locations on the interior (or exterior, or interior/exterior) of components and to deposit into difficult geometries (such as “Y” or “T” shapes).

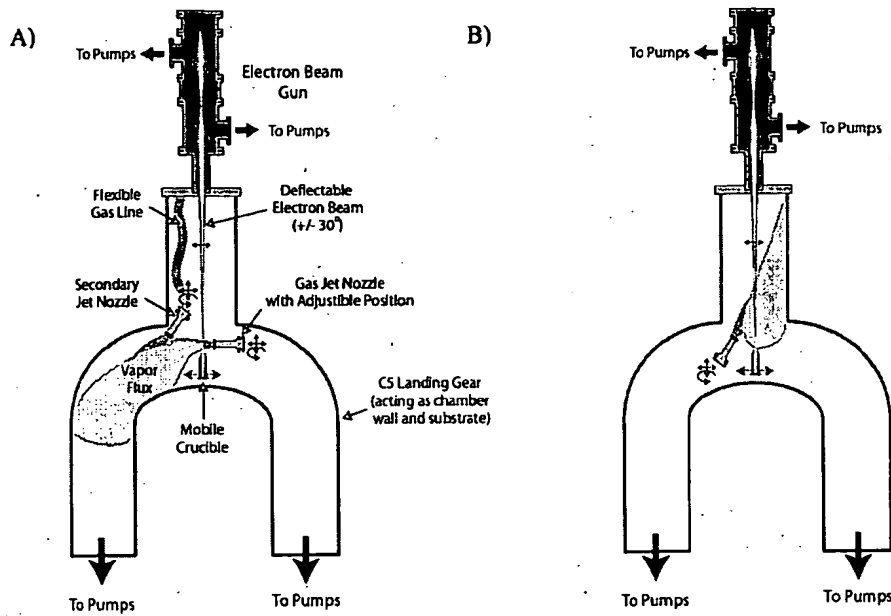


Figure 3' – A) Schematic illustration showing the use of a modified directed vapor deposition approach to coat the interior regions of a C5 landing gear component. In this case, the component acts as both the vacuum chamber and the substrate. By placing a mobile crucible in a central region of the component the vapor flux can be directed onto the interior surfaces of the entire component with the use of multiple gas jet nozzles. **B)** The nozzle placement is altered to change the region of the substrate that is coated.

PUBLICATIONS AND REFERENCES

The following references, publications, applications, and patents are hereby incorporated by reference herein in their entirety:

International Application No. PCT/US03/12920, filed April 25, 2003, filed April 25, 2003, entitled "Apparatus and Method for Uniform Line of Sight and Non-Line of Sight Coating at High Rate;"

D.D. Hass, Y. Marciano and H.N.G. Wadley, "Physical Vapor Deposition on Cylindrical Substrates", *Surf. Coat. and Technol.* (2003) in press;

International Application No. PCT/US03/37485, filed November 21, 2003, entitled "Bond Coat for a Thermal Barrier Coating System and Related Method thereof;"

International Application No. PCT/US03/36035, filed November 12, 2003, entitled "Extremely Strain Tolerant Thermal Protection Coating and Related Method and Apparatus Thereof,"

International Application No. PCT/US03/23111, filed July 24, 2003, entitled "Method and Apparatus for Dispersion Strengthened Bond Coats for Thermal Barrier Coatings;"

International Application No. PCT/US02/28654, filed September 10, 2002, entitled "Method and Apparatus for Application of Metallic Alloy Coatings;"

U.S. Pat. No. 5,534,314, filed August 31, 1994, entitled "Directed Vapor Deposition of Electron Beam Evaporant;"

U.S. Pat. No. 5,736,073, filed July 8, 1996, entitled "Production of Nanometer Particles by Directed Vapor Deposition of Electron Beam Evaporant;"

U.S. Pat No. 6,478,931 B1, filed August 7, 2000, entitled "Apparatus and Method for Intra-layer Modulation of the Material Deposition and Assist Beam and the Multilayer Structure Produced Therefrom," and corresponding Divisional U.S. Application No. 10/246,018, filed September 18, 2002;

International Application No. PCT/US01/16693, filed May 23, 2001 entitled "A process and Apparatus for Plasma Activated Deposition in a Vacuum," and corresponding U.S. Application No. 10/297,347, filed Nov. 11, 2002; and

International Application No. PCT/US02/13639, filed April 30, 2002 entitled "Method and Apparatus for Efficient Application of Substrate Coating."

International Application No. PCT/US04/24232, filed July 28, 2004, entitled "Method for Application of a Thermal Barrier Coating and Resultant Structure thereof."

Some aspects of some of the embodiments of the present invention method and system include, but not limited thereto, the following uses:

- Coatings for military gun barrels and rifle barrels or the like,
- Coatings for aircraft landing gear or the like, and/or
- Coatings for actuators in suspension control systems or the like.

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